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EVALUATING THE ADHERENCE TO THE SUBSTRATE OF FIBER REINFORCED PLASTER MORTARS

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Abstract: *Due to the constant evolution of the consumer market, new building materials appear continuously. One such product is the new developed composite plaster mortar. The main purpose of the current research is to evaluate the adherence to the support layer of plaster mortars reinforced with polypropylene synthetic fibers. In this experimental study, sets of 2 samples of each recipe were materialized on the substrate of solid bricks. It is intended an analysis of the mechanical characteristics of the material, in order to indicate a specific amount of fibers in the matrix and to recommend some proper application areas.*

Key words: *polypropylene; synthetic fibers; adherence; plaster mortar; composite; reinforcement*

1.Introduction

The present paper starts from the idea that the advantages of fibers introduced in mortars should all be harnessed.

At present, in our domestic market, one can find only a limited range of fiber reinforced composite mortars, mainly used in many precast components, in horizontal floors, blankets or similar elements and less in plasters, where the research seems to be less directed. [1]

2.Objectives

In this study, the influence of different doses of fiber reinforcement upon the adhesion of plaster mortars is investigated.

This new developed composite material is obtained through a simple technology, by the addition of the required mass of polypropylene fibers and mixing about five minutes to achieve a proper dispersal.

The evaluation of the adherence to the substrate of these plaster mortars is studied by comparing the results of various fiber doses (1.00kg/m^3, 1.50kg/m^3, 2.00kg/m^3 and 3.00kg/m^3). Also, the influence of reinforcement upon tensile strength characteristics is discussed.

For the fabrication of the mortars to be tested, 12 mm long synthetic fibers (PP) were used, along with six different recipes and two control recipes (with no reinforcement).

Table 1 shows several physical and mechanical characteristics of different types of fibers, including polypropylene.

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Different fiber properties [2][3][4] Table 1

Fiber type	Diameter D *[μ]*	Density ρ *[kg/m³]*	Tensile strength R_t *[kN/mm²]*	Elasticity module E *[kN/mm²]*	Elongation at break *[%]*
Steel	5÷800	7850	1.0÷3.0	210	3÷4
Glass	9÷15	2500	1.0-4.0	70÷80	1.5÷3.5
Polypropylene (PP)	10÷200	900	0.5÷0.8	35÷50	20÷25
Carbon (PAN-IM)	8÷9	1780÷1820	2.41÷2.93	228÷276	1.0
Carbon (PAN-UHM)	7÷10	1860	1.72	517	0.3÷0.4
Kevlar	12	1479	2.80÷3.79	131	2.2÷2.8
Polyester	20÷200	950	0.7÷0.9	8.4	11÷13
Polyethylene	20÷200	950	0.70	0.14÷0.42	10
Mineral wool	10	2700	0.5÷0.8	70÷120	0.6
Asbestos	0.02÷20	3200	0.5÷3.0	80÷150	0.5÷2.0
Polycrystalline alumina	500÷770	3900	0.65	245	-
Sisal	10÷50	1500	0.80	-	3
Cotton	-	1500	0.4÷0.7	5.0	3÷10

3.1. Material and Methods

For the mineral cement matrix, river sand, without impurities, dug in the sorting station, of grain size 0÷4*mm* was used together with lime hydrated according to EN 459/1/CL80-S, clean water and Portland cement CEM II/B-M (S-LL) 42,5N of initially common strength; its main components are the Portland clinker (K) between 65 - 79% and a mixed admixture of grain slag (S) and limestone (LL), forming 21 - 35% of the composition, according to SR EN 197-1:2002. [1] [5]

In this test, the pattern of fibers used was Edifiber3® Multi, a multifilament fiber type, available on our domestic market, manufactured from 100% pure high density polypropylene by a conventional extrusion process, having a diameter of approx. 10*μm*, a tensile strength of *480N/mm²* and a melting temperature of 165*°C*, according to the product data sheet [6], properties that fit the general physical and mechanical characteristics of polypropylene fibers, listed in Table 1 above.

3.2. Establishing the Formulae and Testing Specimens

The specimens were manually cast in according to eight mortar formulae in the Laboratory of the Faculty of Civil Engineering, department of Building materials, Cluj-Napoca.

For testing tensile strength capabilities, standard 40x40x160*mm* patterns were used (Figure 1) and for evaluating the adherence to the substrate, a plaster layer of 10*mm* thick was applied to the surface of a brick (Figure 2) in order to prepare two circular specimens of 50*mm* diameter.

Fig. 1. *Standard metallic patterns*

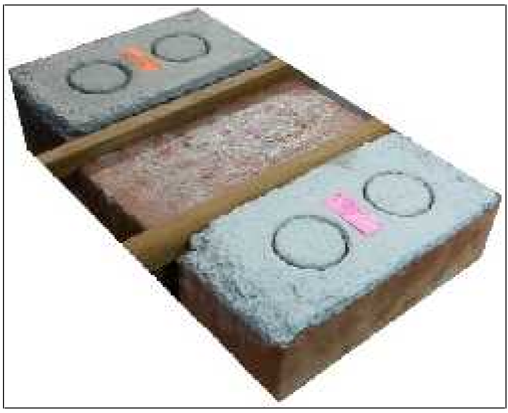

Fig. 2. *Preparing the brick for plastering*

After the grout has hardened, a round metallic pull-off tester (Figure 3) was bonded on the surface of each sample in order to facilitate the attachement of the testing device to the specimens.

Fig. 3. *Metallic pull-off testers*

The specimens were kept up to 7 days in a wet air box at (20±4)*°C* and over 90*%* humidity and then were moved to a (65±5)*%* humidity room, at the same constant temperature of (20±4)*°C*. [1]

Tensile strength was investigated with the Fruhling-Michaelis device (Figure 4.a) at 3, 7 and 28 days, while adhesion to the substrate was tested with a Controls Pull-Off device (Figure 4.b) only after 28 days.

Fig. 4. *a) Tensile strength testing device and b) Adherence testing device*

The calculation relationships applied to the results in case of the adherence was:

$$f_t = \frac{3 \cdot F \cdot l}{2 \cdot b^3} \quad (1)$$

and regarding the tensile strength:

$$f_u = \frac{F_u}{A} \quad (2)$$

The dosages and the components of plaster formulae are detailed in table 2, as follows:

R1-M.P. is a market available material, while R2-M.R. represents an own formulae mortar, none of which is reinforced.

The next Rf3, Rf4, Rf5, Rf6, Rf7 and Rf9 are reinforced composite mortars with various dosages of polypropylene fibers, as mentioned above.

As the unit of measurement, the recipes are relative to 1 cubic meter.

The plaster mortars formulae Table 2

Crt. no.	Mortar type	Formulae (volumes)			
R1	M.P.	[1m^3]	1500 kg – dry material	[6.67l]	10.00 kg - dry material
			280 l - water		1.87 l - water
R2	M.R.	[1m^3]	171 kg - cement 42,5	[7.00l]	1.197 kg - cement 42,5
			260 kg – hydrated lime		1.82 kg - hydrated lime
			1500 kg - sand		10.50 kg - sand
			water - for 9cm consist.		2.50 l - water
Rf3	M.P. + F.PP 1.0kg/m^3	[1m^3]	1500 kg - dry material	[7.33l]	11.00 kg - dry material
			280 l - water		2.053 l - water
			1.0 kg - PP fibers		7.33 gr - PP fibers
Rf4	M.R. + F.PP 1.0kg/m^3	[1m^3]	171 kg - cement 42,5	[7.00l]	1.197 kg - cement 42,5
			260 kg - hydrated lime		1.82 kg - hydrated lime
			1500 kg - sand		10.50 kg - sand
			water - for 9cm consist.		2.50 l - water
			1.0 kg - PP fibers		7 gr - PP fibers
Rf5	M.P. + F.PP 1.5kg/m^3	[1m^3]	1500 kg – dry material	[7.33l]	11.00 kg – dry material
			280l - water		2.053 l - water
			1.5 kg - PP fibers		11 gr - PP fibers
Rf6	M.R. + F.PP 1.5kg/m^3	[1m^3]	171 kg - cement 42,5	[7.00l]	1.197 kg - cement 42,5
			260 kg - hydrated lime		1.82 kg - hydrated lime
			1500 kg - sand		10.50 kg - sand
			water - for 9cm consist.		2.50 l - water
			1.5 kg - PP fibers		10.5 gr - PP fibers
Rf7	M.R. + F.PP 2.0kg/m^3	[1m^3]	171 kg - cement 42.5	[11.0l]	1.881 kg - cement 42,5
			260 kg - hydrated lime		2.86 kg - hydrated lime
			1500 kg - sand		16.50 kg - sand
			water - for 9cm consist.		3.925 l - water
			2.0 kg - PP fibers		22 gr - PP fibers
Rf9	M.P. + F.PP 3.0kg/m^3	[1m^3]	1500 kg - dry material	[7.33l]	11.00 kg - dry material
			280 l – drinking water		2.053 l – drinking water
			3.0 kg – PP fibers		22 gr - PP fibers

In Figure 5 below, the samples can be observed after plastering the brick:

Fig. 5. *The brick after plastering*

In Figure 6 the pattern and the three specimens after casting can be seen:

Fig. 6. *The specimens after casting*

4. Results and Discussions

The experimental results have highlighted the influence of the PP fiber reinforcement upon the mechanical characteristics of cement based composite mortars, in both a commercially available mortar and a mortar designed by the author, as seen in Table 3. [1]

Recording of the results Table 3

Crt. no.	Mortar type	Age [days]	Adherence to the substrate f_u [N/mm^2]	Flexural tensile strength f_t [N/mm^2]
R1	M.P.	3	-	0.48
		7	-	0.70
		28	0.011	1.28
R2	M.R.	3	-	0.51
		7	-	0.73
		28	0.031	1.25
Rf3	M.P. + F.PP 1,0kg/m^3	3	-	0.61
		7	-	0.75
		28	0.010	1.30
Rf4	M.R. + F.PP 1,0kg/m^3	3	-	0.47
		7	-	0.67
		28	0.017	1.20
Rf5	M.P. + F.PP 1,5kg/m^3	3	-	0.55
		7	-	0.70
		28	0.038	1.27
Rf6	M.R. + F.PP 1,5kg/m^3	3	-	0.83
		7	-	1.00
		28	0.015	0.83
Rf7	M.R. + F.PP 2,0kg/m^3	3	-	0.51
		7	-	0.64
		28	0.009	0.95
Rf9	M.P. + F.PP 3,0kg/m^3	3	-	0.60
		7	-	0.91
		28	0.013	0.93

The composition was homogenized and applied by hand, the substrate being wetted in advance.

In case of tensile strength, improvements in mechanical characteristics can be achieved by a mechanized mixing and proper compacting process.

Similarly, in case of adherence, mixing and manner of application plays a significant role. On manual application, the mortar is projected with a certain force over the masonry and also, when applied with the grout pump, it hits the substrate at a constant speed. By implementing this force, a physical connection is achieved (creating a "particular" contact), along with chemical bonds that appear during material hardening.

On the screen capture of the device in Figure 7 the amount of force applied to the sample (on the left, in *kN*) and the calculated resistance value (on the right, in *MPa*) can be distinguished. The “blank space” is to be considered “zero” value.

For an objective discussion of the results, a graphical analysis of the data is listed in the chart below (Figure 8).

Fig. 7. *Screenshot of the recorded values*

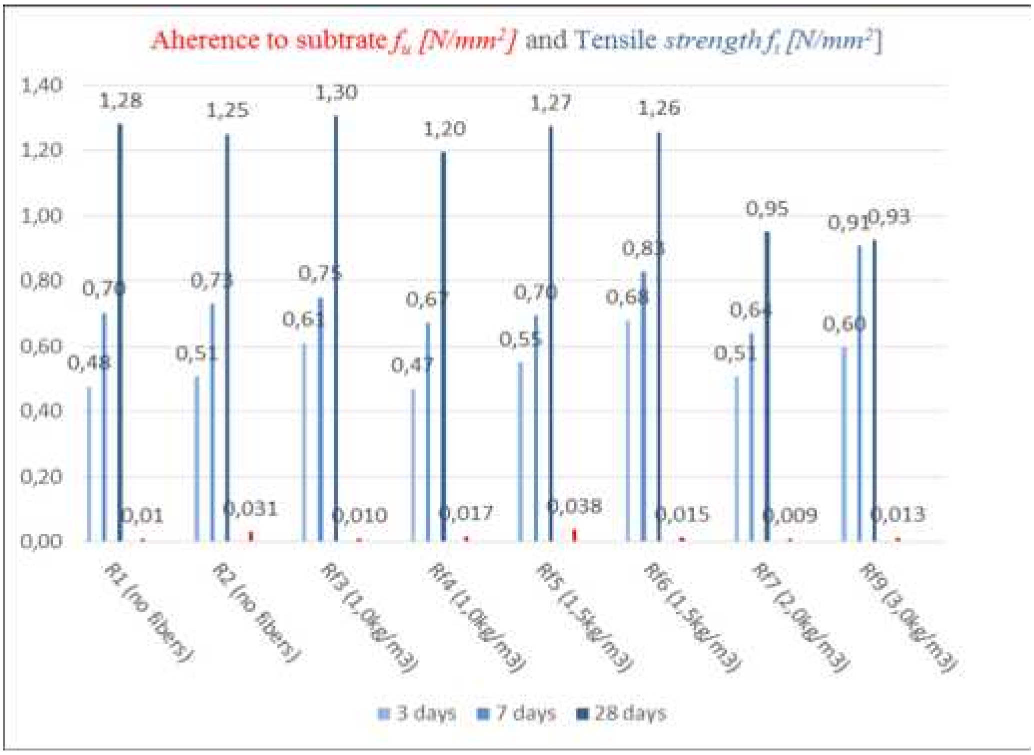

Fig. 8. *Comparative results for the adherence to substrare and flexural tensile strength*

5. Conclusions

Fiber orientation is an important yet difficult to control factor because of the random dispersion of the fibers in the matrix. This fact occurs mainly in thicker sections [7], where the material thickness exceeds the length of the fibers, allowing orientation in all 3 directions (x, y, z).

Concerning the tensile strength, the results are significantly similar and it was appreciated that they may be increased, in favor of composite mortar, by indicating an optimal dosage of 0.90 ÷ 1.00kg/m^3 for the polypropylene fibers (avoiding excessive agglomeration of the matrix), by performing an appropriate mixing and compacting.

These conditions above are essential for removing air from material mass in order to obtain a homogeneous composite as more compact and less porous.

Regarding adhesion to the substrate, it is concluded that this characteristic depends more on the matrix and less on the fiber reinforcement, because the synthetic fibers does not penetrate into support layer.

If the matrix adheres well to the substrate, then no separation from support layer occurs, but a split in the material structure (Figure 9).

Fig. 9. *Breaking of the matrix structure*

Therefore, the pullout efforts are being transferred to the composite and by default to the fibers, whose role is now decisive.

Different manners of breaking can be remarked in Figure 10.a and Figure 10.b. Factors that directly influence these physical and mechanical behaviors were mentioned above.

Fig. 10. *a) Separation from the substrate*

Fig. 10. *a) Various manners of breaking*

In terms of application area, this new composite mortar can be successfully used as interior plaster for churches, preparing base layer for painting and successfully replacing hemp fibers. Also, the mortar can be used for restoration and consolidation of monuments and other old buildings.

For future research, 6 to 8*mm* long polypropylene fibers will be used together with mechanized mixing, performing multiple measurements on the same recipe, so that the average of the measured results to be most relevant.

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